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Title: ANSI/ANS-8 Criticality Safety Standards

Author(s): McCallum, Jacob Bryan
Brown, Alexander Barton
Kuropatwinski, James J.

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Los Alamos
NATIONAL LABORATORY
EST. 1943

ANSI/ANS-8 Criticality Safety Standards

Jacob McCallum

Alex Brown

James Kuropatwinski

Criticality Safety Analysts

Los Alamos National Laboratory

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NNSA
National Nuclear Security Administration

Agenda

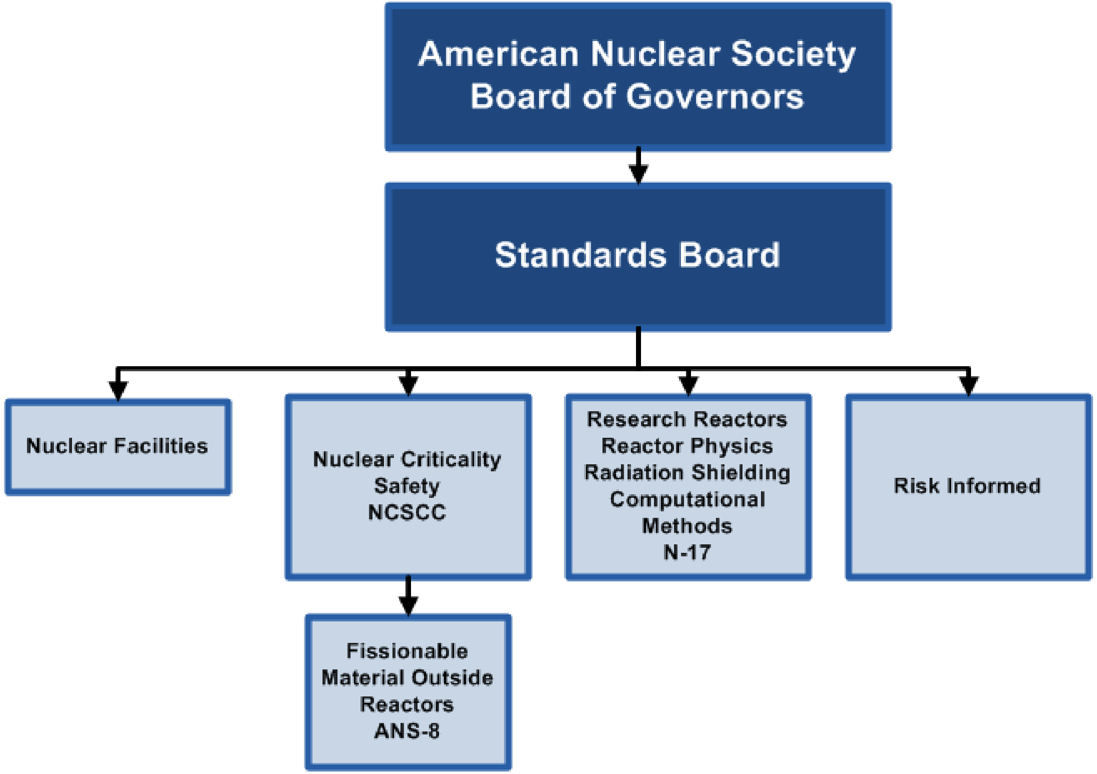
- **Standards Organization and Structure**
- **Review of Select Standards**

ANSI/ANS-8 Standards

Standards Organization & Structure

- American National Standards Institute (ANSI) – accrediting authority
  - Licenses or certifies organizations to develop American National Standards (ANS)
- Standards are comprised of consensus industry best practices
- Consensus involves stakeholders made up of:
  - Product and/or service organizations
  - Users
  - Other interested parties
- Responsible Organizational Member: American Nuclear Society

Organization & Structure



Organization & Structure

- General types of ANSI/ANS Series 8 standards :
    1. Administrative
    2. Application
    3. Emergency response

- Each has a functional domain:
    - History and development process boundaries not always crisp
    - Detailed standards for specific topics have been developed to address industry growth

- *If a standard applies, compliance is not optional*

ANSI/ANS Series 8 Categories

Administrative		Application Specific			Emergency
8.1	8.20	8.5	8.12	8.17	**8.3**
8.10	8.24	8.6	8.14	8.21	8.23
8.19	8.26	8.7	8.15	8.27	

List of ANSI/ANS 8 Standards

- ANSI/ANS-8.1: Nuclear Criticality Safety in Operations with Fissionable Material Outside Reactors
- ANSI/ANS-8.3: Criticality Accident Alarm System (CAAS)
- ANSI/ANS-8.5: Use of Borosilicate-Glass Raschig Rings as a Neutron Absorber in Solutions of Fissile Material
- ANSI/ANS-8.6: Safety in Conducting Subcritical Neutron-Multiplication Measurements in Situ
- ANSI/ANS-8.7: Nuclear Criticality Safety in the Storage of Fissile Materials

List of ANSI/ANS-8 Standards (cont.)

- ANSI/ANS-8.10: Criteria for NCS Controls for Operations with Shielding and Confinement
- ANSI/ANS-8.12: Nuclear Criticality Control and Safety of Plutonium-Uranium Fuel Mixtures Outside Reactors
- ANSI/ANS-8.14: Use of Soluble Neutron Absorbers in Nuclear Facilities Outside Reactors
- ANSI/ANS-8.15: Nuclear Criticality Control of Special Actinide Elements
- ANSI/ANS-8.17: Criticality Safety Criteria for the Handling, Storage, and Transportation of LWR Fuel Outside Reactors

List of ANSI/ANS-8 Standards (cont.)

- ANSI/ANS-8.19: Administrative Practices for Criticality Safety
- ANSI/ANS-8.20: Nuclear Criticality Safety Training
- ANSI/ANS-8.21: Use of Fixed Neutron Absorbers in Nuclear Facilities Outside Reactors
- ANSI/ANS-8.22: Nuclear Criticality Safety Based on Limiting and Controlling Moderators
- ANSI/ANS-8.23: Nuclear Criticality Accident Emergency Planning and Response

List of ANSI/ANS-8 Standards (cont.)

- ANSI/ANS-8.24: Validation of Neutron Transport Methods for Nuclear Criticality Safety Calculations

- ANSI/ANS-8.26: Criticality Safety Engineer Training and Qualification Program

- ANSI/ANS-8.27: Burn-up Credit for LWR Fuel

ANSI/ANS-8.1

- Title: Nuclear Criticality Safety in Operations with Fissionable Material Outside Reactors
- Purpose
  - Provide guidance for the prevention of criticality accidents in the handling, storing, processing, and transportation of fissionable material.
    - The standard by itself cannot establish safe processes in an absolute sense
    - Good operating practices, as embodied in the standard, must be adhered to maintain the favorable safety record
- Key Requirements
  - Process analysis requirement: operations with fissionable material shall be subcritical under normal and credible abnormal conditions
  - Written procedures: operations involving fissionable material shall be governed by written procedures
  - Annual Reviews: operations shall be reviewed at least annually to ascertain that procedures are being followed and process conditions have not been altered

ANSI/ANS-8.1 (cont.)

- Recommendations
  - Double contingency principle: designs should incorporate features such that two unlikely, independent, concurrent changes in process conditions must occur before criticality is possible
  - Control of NCS parameters may be exercised through physical restraints, instrumentation, etc.
  - Reliance should be placed on equipment design rather than on administrative controls

ANSI/ANS-8.1 – Limits

Table 1 – Single-parameter subcritical limits for uniform aqueous solutions of fissile nuclides

Parameter	Subcritical limit for fissile solute				
	$^{233}UO_2F_2$ [15]	$^{233}UO_2(NO_3)_2$ [15]	$^{235}UO_2F_2$ [16]	$^{235}UO_2(NO_3)_2$ [16]	$^{239}Pu(NO_3)_4$ [16]
Mass of fissile nuclide (kg)	0.54	0.55	0.76	0.78	0.48
Diameter of cylinder of solution (cm)	10.5	11.7	13.7	14.4	15.4
Thickness of slab of solution (cm)	2.5	3.1	4.4	4.9	5.5
Volume of solution (L)	2.8	3.6	5.5	6.2	7.3
Concentration of fissile nuclide (g/L)	10.8	10.8	11.6	11.6	7.3
Atomic ratio of hydrogen to fissile nuclide[1)]	2390	2390	2250	2250	3630
Areal density of fissile nuclide (g/cm^2)	0.35	0.35	0.40	0.40	0.25

[1)] Lower limit.

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[4] Use of subcritical limit data provided in ANSI/ANS standards or accepted reference publications does not require further validation.

ANSI/ANS-8.1 – Limits (cont.)

Table 2 – ^{235}U enrichment subcritical limits for uranium mixed homogeneously with water[1)]

Compound	Subcritical Limits (wt% ^{235}U)
Uranium metal	0.93
UO_2, U_3O_8, or UO_3[2)]	0.96
$UO_2(NO_3)_2$	1.96

[1)] See Ref. [16].
[2)] With water content limited to 1.5%, the enrichment limit is increased to 3.2% ^{235}U [16].

Table 3 – Single-parameter subcritical limits for metal units

Parameter	Subcritical limits for		
	^{233}U [15]	^{235}U [16]	^{239}Pu [17]
Mass of fissile nuclide (kg)	6.0	20.1	5.0
Cylinder diameter (cm)	4.5	7.3	4.4
Slab thickness (cm)	0.38	1.3	0.65
Uranium enrichment (wt% ^{235}U)	–	5.0	–
Maximum density for which mass and dimension limits are valid (g/cm^3)	18.65	18.81	19.82

ANSI/ANS-8.1 – Limits (cont.)

Table 4 – Single-parameter subcritical limits for oxides containing no more than 1.5% water by weight at full density

Parameter	$^{233}UO_2$ [15]	$^{233}U_3O_8$ [15]	$^{233}UO_3$ [15]	$^{235}UO_2$ [16]	$^{235}U_3O_8$ [16]	$^{235}UO_3$ [16]	$^{239}PuO_2$ [17]
Mass of fissile nuclide (kg)	10.1	13.4	15.2	32.3	44.0	51.2	10.2
Mass of oxide (kg)[1)]	11.7	16.0	18.7	37.2	52.8	62.6	11.5
Cylinder diameter (cm)	7.2	9.0	9.9	11.6	14.6	16.2	7.2
Slab thickness (cm)	0.8	1.1	1.3	2.9	4.0	4.6	1.4
Maximum bulk density for which limits are valid (g/cm^3)[2)]	$\frac{9.38}{1-0.085(1.5-w)}$	$\frac{7.36}{1-0.065(1.5-w)}$	$\frac{6.56}{1-0.056(1.5-w)}$	$\frac{9.44}{1-0.086(1.5-w)}$	$\frac{7.41}{1-0.065(1.5-w)}$	$\frac{6.60}{1-0.057(1.5-w)}$	$\frac{9.92}{1-0.091(1.5-w)}$

[1)] These values include the mass of any associated moisture up to the limiting value of 1.5% by weight.
[2)] w represents the quantity of water, in wt % in the oxide

Table 5 – Single-parameter subcritical limits for oxides containing no more than 1.5% water by weight at no more than half density[1)]

Parameter	$^{233}UO_2$ [15]	$^{233}U_3O_8$ [15]	$^{233}UO_3$ [15]	$^{235}UO_2$ [16]	$^{235}U_3O_8$ [16]	$^{235}UO_3$ [16]	$^{239}PuO_2$ [17]
Mass of fissile nuclide (kg)	23.4	30.5	34.7	88	122	142	27
Mass of oxide (kg)[2)]	27.0	36.6	42.4	102	146	174	30
Cylinder diameter (cm)	11.9	14.8	16.3	20.4	26.0	28.8	12.6
Slab thickness (cm)	1.6	2.2	2.6	5.8	8.0	9.3	2.8

[1)] These are half the maximum bulk densities of Table 4.
[2)] These values include the mass of any associated moisture up to the limiting value of 1.5% by weight.

ANSI/ANS-8.3

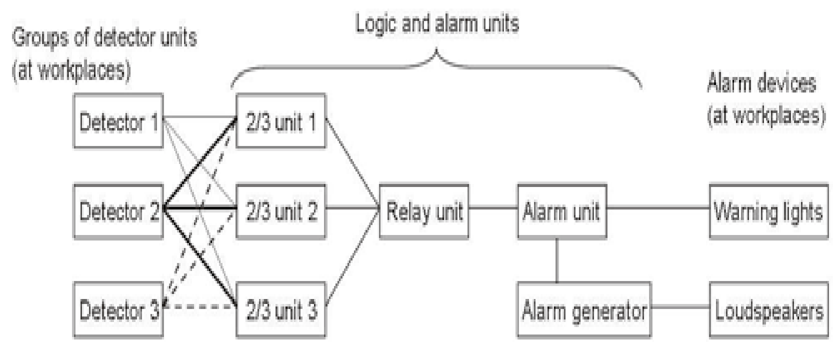
- Title: Criticality Accident Alarm System (CAAS)
- Purpose
  - CAAS: provides indication that a criticality accident has occurred and notify personnel to evacuate
  - 8.3 gives guidance for establishment and maintenance of CAAS
  - Portable CAAS specifically addressed
  - This is NOT for emergency response (8.23)
- Key Requirements
  - Need for a CAAS shall be evaluated when inventory exceeds SPLs from 8.1
  - CAAS shall be installed when personnel would be subject to excessive radiation does
  - CAAS shall be designed to detect minimum accident of concern
  - Dependability, sensitivity, system design also have many requirements
  - Installation of CAAS should reduce overall risk to personnel (trivial vs. risk reduction)

ANSI/ANS-8.3 (cont.)

- Recommendations
  - CAAS should remain operational in event of seismic event
  - Audio generators of CAAS should produce sound pressure level of at least 75 dB but not less than 10 dB above ambient noise
  - Components of CAAS should be located to minimize damage from fire, etc.
- Technical practices/applications
  - Always analyze minimum accident of concern for detector placement
  - Ensure alarm is audible or provide visual notification in high noise areas
  - EPDs are also used in high noise areas or outside of CAAS coverage
  - Use portable compliant detectors if CAAS is down

ANSI/ANS-8.3 – CAAS Unit

Example of a CAAS unit and typical logic:



ANSI/ANS-8.7

- Title: Nuclear Criticality Safety in the Storage of Fissile Materials
- Purpose:
  - Provides subcritical mass limits permitted for fissionable material in storage for regular (i.e., repeated, consistent) arrangements
  - Not a substitute for a detailed CSED
  - Experienced individuals still needed to identify contingencies for the operation
- Key Requirements
  - Operations conducted in accordance with 8.1
  - Methods of control and operational practice shall be described in written procedures; limits shall be posted
  - Fissile material shall be stored such that NPH events are not a concern

ANSI/ANS-8.7 (cont.)

- Recommendations
  - Design of structures should preclude unacceptable configurations (minimize reliance on admin controls)
  - Spacing may be maintained by use of fixtures or physical barriers
  - Storage areas should contain no combustible materials
- Useful Tables:

Table 5.7
Unit Mass Limit in Kilograms of Plutonium per Cell in Water-Reflected Storage Arrays: Metal, 100 wt-% ^{239}Pu

Number of Units in Cubic Storage Arrays	*Minimum Dimension of Cubic Storage Cell (mm)*					
	254	305	381	457	508	610
(H/Pu $\leq$ 0.01; Pu density $\leq$ 19.7 g/cm^3)						
64	3.4	4.1	4.9	5.5[a]	5.8[a]	6.3[a]
125	2.9	3.6	4.4	5.1[a]	5.4[a]	6.0[a]
216	2.6	3.2	4.1	4.7	5.1[a]	5.7[a]
343	2.3	2.9	3.8	4.4	4.8[a]	5.4[a]
512	2.1	2.7	3.5	4.2	4.6	5.2[a]
729	1.9	2.5	3.3	3.9	4.3	5.0[a]
1000	1.7	2.3	3.1	3.7	4.1	4.8

[a] Values are greater than 90 % of critical spherical mass, water reflected.

ANSI/ANS-8.15

- Title: Nuclear Criticality Controls of Special Actinide Elements
- Purpose:
  - Guidance for the prevention of criticality accidents in the handling, storing, processing, and transporting of special actinide elements
  - 8.15 is an extension of 8.1
  - Provides subcritical mass limits for fourteen nuclides
  - Acknowledges that the subcritical mass limits may be much less than the actual critical mass values; this is done to account for the calculational uncertainties

ANSI/ANS-8.15 – Limits

Table 1 – Subcritical mass limits for unreflected, water-reflected, and steel-reflected spherical metal systems (kilograms)

Nuclide	Crystallographic density (g/cm³)[1]	Subcritical mass limit (kg)		
		Unreflected	Water-reflected[2]	Steel-reflected[3]
^{232}U	18.681	1.7	1.0	0.9
^{234}U	18.842	64.	59.	34.
^{237}Np	20.476	39.	35.	21.
^{236}Pu	19.601	3.3	1.7	1.6
^{238}Pu	19.768	6.3	5.1	3.3
^{240}Pu	19.934	27.	20.	15.
^{241}Pu	20.017	8.9	3.7	3.7
^{242}Pu	20.101	60.	55.	40.
^{241}Am	13.660	30.	24.	16.
^{242m}Am	13.717	4.5	1.6	1.7
^{243}Am	13.774	70.	65.	45.
^{242}Cm	13.407	8.	6.	4.
^{243}Cm	13.463	3.7	1.4	1.4
^{244}Cm	13.518	14.	11.	7.
^{245}Cm	13.574	3.4	1.3	1.3
^{246}Cm	13.629	19.	16.	10.
^{247}Cm	13.685	3.5	1.5	1.4
^{249}Cf	15.110	3.1	1.2	1.4
^{251}Cf	15.232	1.3	0.6	0.6

[1] For practical purposes, crystallographic density is the maximum density of the nuclide under conditions of standard temperature and pressure (see Ref [3]).
[2] The water reflector is 15 cm of water.
[3] The steel reflector is 20 cm of SS304.

ANSI/ANS-8.15 – Limits (cont.)

Table 2 – Subcritical mass limits for nuclides in metal-water mixtures (grams)*

Nuclide	Nuclide concentration at minimum critical mass (g/cm^3)	Subcritical mass limit (Grams)		
		Unreflected (g)	Water-reflected[1)] (g)	Steel-reflected[2)] (g)
^{236}Pu	0.150	1100.	600.	450.
^{241}Pu	0.022	360.	185.	140.
^{242m}Am	0.0025	21.	11.	9.
^{243}Cm	0.028	190.	90.	80.
^{245}Cm	0.009	58.	23.	22.
^{247}Cm	0.180	1,000.	500.	350.
^{249}Cf	0.014	20.	10.	10.
^{251}Cf	0.004	10.	5.	5.

[1)] The water reflector is 15 cm of water.
[2)] The steel reflector is 20 cm of SS304.
* These metal-water mixtures have minimum critical masses that are smaller than the metal critical mass.

ANSI/ANS-8.19

- Title: Administrative Practices for Criticality Safety
- Purpose:
  - Overarching purpose: to provide consistency in the NCS program administrative practices given the diverse backgrounds of the various NCS programs
  - Provide more definitive guidance for what NCS staff members should be involved in
- Key Requirements
  - Provides an expansion of requirements from 8.1 in:
    - Management responsibilities, supervisory responsibilities, NCS staff responsibilities, operating procedures, process evaluation for NCS, material control, and response to criticality accidents
- Recommendations consistent with those of 8.1

ANSI/ANS-8.20

- Title: NCS Training
- Purpose:
  - Gives outlines, procedures and responsibilities for developing appropriate NCS training for employees associated with fissionable material operations outside reactors
  - Provisions are given for training objectives, designation of personnel requiring training, framework for training program content, and criteria for program documentation and evaluation
  - Target audience: those who work in or near facilities with potential for criticality accident including FMHs and supervisors, operations support personnel, design and maintenance personnel, emergency response personnel, managers, others
  - Program Content:
    - Fission Chain Reactions and Accident Consequences
    - Neutron Behavior in Fissioning Systems
    - Criticality Accident History
    - Response to Criticality Alarm Signals
    - Control Parameters
    - Policy and Procedures

ANSI/ANS-8.23

- Title: Nuclear Criticality Accident Emergency Planning and Response
- Purpose:
  - Provides criteria for emergency planning and response to a nuclear criticality accident for facilities that process/store/handle fissionable material
  - It assumes an alarm system per 8.3 is in place
  - It is specific to a criticality accident, not for general emergency planning and response
- Emergency response plan may be activated on any indication that a criticality accident is developing, is occurring, or has occurred
- Evacuation routes should be planned to minimize total risk from all hazards (chemical, industrial, radiation)

ANSI/ANS-8.23 (cont.)

- Key Requirements:
  - Management responsibilities:
    - Shall ensure staff with relevant expertise is provided, an emergency response plan is established (and exercised), IEZ and evacuation routes are established, instrumentation and equipment are provided to respond
  - Technical staff responsibilities:
    - Identify potential accident locations, characterize potential accidents, define IEZ, participate in planning, conduct, evaluation of drills
  - Emergency response planning
    - Potential accident locations and accident characteristics shall be evaluated and documented to assist emergency planning
    - IEZ shall be established based on this (documented) evaluation
  - Other major areas:
    - Evacuation
    - Reentry/rescue
    - Training and drills

ANSI/ANS-8.26

- Title: Criticality Safety Engineer Training and Qualification Program
- Purpose:
  - Provides content of technical and operational training for NCS engineers, but does not specify how to do it
    - Technical ***and*** operational experience necessary to qualify as NCS engineer
  - Competencies necessary for NCS engineer qualification (Section 7 of 8.26):
    - Degree and educational background
    - Methods
    - Critical experiments and data
    - Hands-on experiments
    - Rules, standards, and guides
    - Nuclear criticality safety evaluations
    - Safety analyses and controls
    - Criticality alarm systems
    - Material accountability and nondestructive analysis practices
    - Process and facility knowledge